Assessment on WEPP Model Applicability to the Loess Plateau of China

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1. Abstract

The objectives of this study were to assess the WEPP model's ability to predict runoff and soil erosion at steep slopes in the hilly-gully region of the Loess Plateau and to provide insights for adapting it for the Loess Plateau. Field runoff and soil loss data collected from six bare gradient plots at the Ansai experimental station during 1985-1992 were used to calibrate, validate, and evaluate the WEPP hillslope model. Measured rainfall intensity (rainfall breakpoint data) was directly used to minimize climate-induced errors. Overall, the calibrated WEPP model predicted event, annual, and average annual runoff and soil loss for different slope gradients reasonably well. Measured runoff tended to increase with slope steepness, but simulated runoff was somewhat insensitive to slope degree change. However, simulated average annual soil loss, though satisfactory, was slightly oversensitive to slope changes. Extreme rainfall events had great impacts on simulated runoff and soil loss

2. Introduction

The Loess Plateau is one of the most severely eroded areas in the world due to frequent large rainfall storms in summer months, steep landscape, low vegetable cover, and highly erodible loessial soil. In order to quantitatively evaluate soil erosion on the Loess Plateau, erosion models have been studied rigorously in China. Since 1980s, great efforts have been made to adopt the Universal Soil Loss Equation (USLE) (Wischmeier *et al*., 1978) in the mainland of China. As a result, many regional soil loss prediction models at hillslope scales based on variant modifications of USLE were developed to predict soil erosion for various physiographic regions ((Zheng *et al*.; 2004).

The Water Erosion Prediction Project (WEPP) model (Nearing *et al*., 1989) was parameterized and validated extensively for gentle slopes (Zhang *et al*. 1996; Ghidey and Alberts, 1996). In recent years, several studies were carried out to evaluate the WEPP model's applicability to Chinese physiographic conditions in different climate regions. Miu *et al*. (2004) tested WEPP in the upper region of the Yangtze River basin in southern China, and reported that WEPP could simulate erosion process satisfactorily for single rain events in the region. Shi *et al*. (2006) evaluated the WEPP model on the Loess Plateau and reported that CLIGEN was adequate to generate climate data for predicting runoff and soil erosion for the station. To date there is no systematic evaluation of the WEPP model's ability to predict runoff and soil erosion on the steep landscapes on the Loess Plateau at high soil erosion rate.

The WEPP model was mainly parameterized and validated for gentle slopes at relatively low soil erosion rate; it would be very useful to know how WEPP performs on steep slopes at high soil erosion rate. This knowledge would validate or invalidate whether the erosion sciences used in WEPP is sound and applicable to severely eroded conditions at steep slopes, and provide insights on how to improve the model if its performance is less satisfactory.

The objective of this study was to assess the WEPP model's ability to predict runoff and soil erosion in the hilly-gully region of the Loess Plateau using field runoff and soil loss data collected from six bare slope plots at the Ansai experimental station during 1985-1992. The research results not only broaden the scopes of the WEPP model's application, but also provide insights for improving it and for developing Chinese versions of soil erosion prediction models.

3. Materials and Methods

Plot Description and Treatment

There were six slope gradient treatment plots (5°, 10°, 15°, 20°, 25°, and 28°), all the plots were 5 m wide, 20 m long, and uniform in slope. All bare plots were continuous bare fallow under conventional tillage. The soil was turned over with a spade to about 0.2 m deep in mid April each year.

Climate Data

Daily weather data measured at the Ansai station from 1985 to 1992 were used. The observed data included daily rainfall breakpoint data, maximum and minimum temperature, solar radiation, wind velocity, wind direction, and dew point temperature. To minimize climate-induced uncertainty in the runoff and soil loss predictions, measured rainfall breakpoint data (reading off charts of cumulative rainfall depth) along with other measured data were used to compile the climate input data for the WEPP model so that the rainfall breakpoint data were directly used in WEPP model's calibration and simulation.

Calibration of Hydraulic Conductivity and Soil Erodibility Parameters

It has been shown that WEPP-predicted runoff is most sensitive to effective hydraulic conductivity (K_s) and soil erosion to rill erodility (K_r) and critical soil shear strength (τ_c) (Nearing et al., 1990). Similar to the method used by Zhang (2004), K_s was varied manually to minimize the sum of squared error (SSE) between annual measured runoff and predicted runoff. Using optimized K_s as an input value, K_r and τ_c were further optimized in a similar fashion by minimizing SSE between annual measured soil loss and predicted values. The slopes of 5°, 15°, and 25° were used in the optimization, and the slopes of 10°, 20°, and 28° were used for validation.

Evaluation Measures

The Nash-Sutcliffe model efficiency (ME) was used in this study. Model efficiency, as defined by Nash and Sutcliffe (1970), is a good measure of agreement between model prediction and measured data, and is calculated as:

$$ME = 1 - \frac{\sum \left(Y_{obs} - Y_{pred}\right)^2}{\sum \left(Y_{obs} - Y_{mean}\right)^2}$$

where Y_{obs} is the observed value, Y_{pred} is the predicted value, and Y_{mean} is the measured mean. The ME can range from $-\infty$ to 1.

4. Results and discussion

Parameter Calibration and Validation

The estimation of three parameters, effective hydraulic conductivity (K_s), rill erodility (K_r), and critical soil shear stress (τ_c). were: K_s =19.3 mm h^{-1}, K_r =0.025 s m^{-1}, and τ_c =2.6 Pa. The measured and calculated annual runoff and soil loss using these three calibrated values were close, and their scatter plots were near the 1:1 line with a ME of 0.91 for runoff (Fig. 1A) and a ME of 0.79 for soil loss (Fig. 1B), indicating that the model fitted the measured annual data well. To validate the model calibration, the model was run for the 10°, 20°, and 28° plots. The MEs between the predicted and measured annual runoff and soil loss were 0.92 and 0.76, respectively, which were similar to the MEs from the calibration plots, indicating that the three calibrated values worked well for the slope gradient treatment.

Simulated Eventual Runoff and Soil Loss

The three key parameters calibrated and measured rainfall intensity (rainfall breakpoint data) were used to simulate eventual and average-annual runoff depths and soil loss rates for the six slope gradient plots. The measured and simulated event runoff and soil loss were close to the 1:1 line, with a ME of 0.92 for runoff depths and a ME of 0.86 for soil loss rates (Fig. 2A, B). The results showed that the WEPP model simulated event runoff quite well; however, it tended to overpredict surface runoff for storm events having high maximum 30-min rainfall intensity (I_{30}). As indicated in Fig. 2A, the runoff depths of the four events having the highest I_{30} in the records were slightly overpredicted (the maximum 30-min intensity was around 60 mm/h for the four storms). The measured event runoff increased with slope steepness primarily due to the decrease in the surface storage capacity, but the simulated runoff was somewhat insensitive to slope increase. The event soil loss was well simulated by the model (Fig. 2B), except for the extreme event on August 3 of 1988, in which 138-mm rain fell within one day and the I_{30} reached to 56 mm/h. It seemed that WEPP underpredicted soil loss for this extreme event at all six slopes. The underprediction might be explained by the fact that only downward scouring by concentrated flow is simulated in the WEPP model while rill headcutting and sidewall slumping are not explicitly modeled. It is well known that the rill headcutting and sidewall slumping are important mechanisms of rill erosion at steep slopes in the Loess Plateau, especially during large erosive storms (Zheng et al, 1987).

Simulated Average-annual Runoff and Soil Loss

Measured and simulated average-annual runoff and soil loss are plotted in Fig. 3 with a ME of 0.62 for runoff and a ME of 0.83 for soil loss. Average annual runoff and soil loss could provide useful insights into model's overall response to slope gradient changes, since the climate factor was largely averaged out. The simulated runoff increased with slope gradient only from 5° to 10°, while the measured runoff increased up to a much steeper slope (Fig. 3A). The WEPP model seemed to consistently overpredict average-annual soil loss (Fig. 3B), and the overprediction seemed to increase as slope gradient increased. This result indicated that the WEPP's response of soil loss prediction to slope gradient change was slightly over sensitive under steep slope conditions.

5. Conclusions

The WEPP hillslope model was evaluated using runoff and soil loss data collected from six bare slope gradient plots during 1985-1992 on the Loess Plateau. The measured rainfall breakpoint data were directly used in the calibration and evaluation to minimize rainfall intensity representation errors. Three key parameters (effective hydraulic conductivity, rill erodibility, and critical soil shear stress) were calibrated and validated with annual runoff and soil loss data. Model efficiencies (ME) calculated for the validation plots were 0.92 for annual runoff and 0.79 for annual soil loss, indicating that the calibration worked well for each treatment.

For different slope gradient, MEs between measured and simulated values were 0.92 and 0.86 for event runoff and soil loss, respectively; and were 0.62 and 0.83 for average-annual runoff and soil loss, indicating that the WEPP model's response of soil loss to slope steepness is satisfactory. The WEPP model seemed to overpredict average-annual soil loss, and the overprediction seemed to increase with slope increase, indicating that the WEPP's response of soil loss to slope gradient was, though acceptable, slightly oversensitive under steep slope conditions. Moreover, at extreme rain events with high I_{30} (over 50 mm/h) and more than 100 mm rainfall per 24 hours, WEPP underpredicted runoff and soil loss on the Loess Plateau.
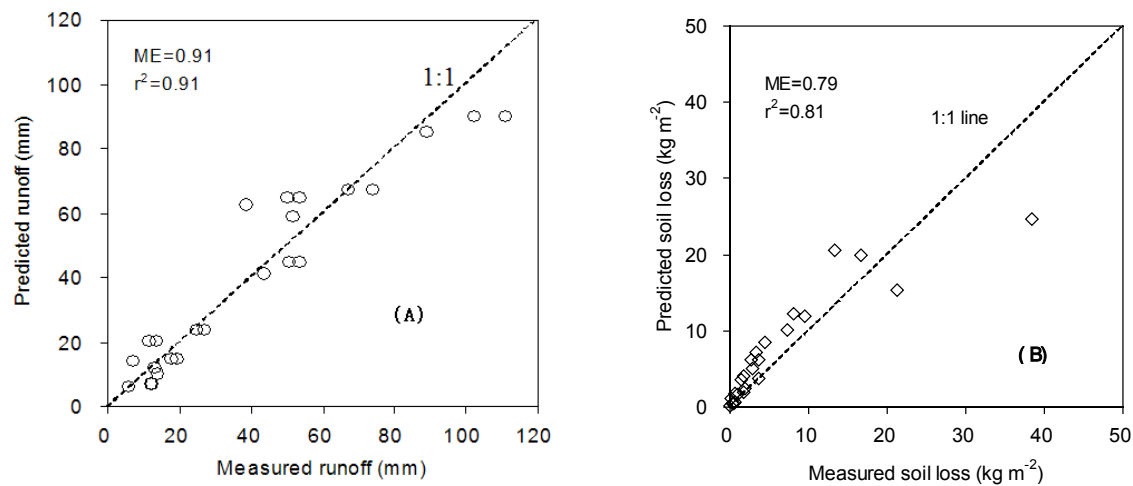

Figure 1 Scatter diagrams between measured and calibrated annual runoff (A) and soil loss (B) on the calibration plots
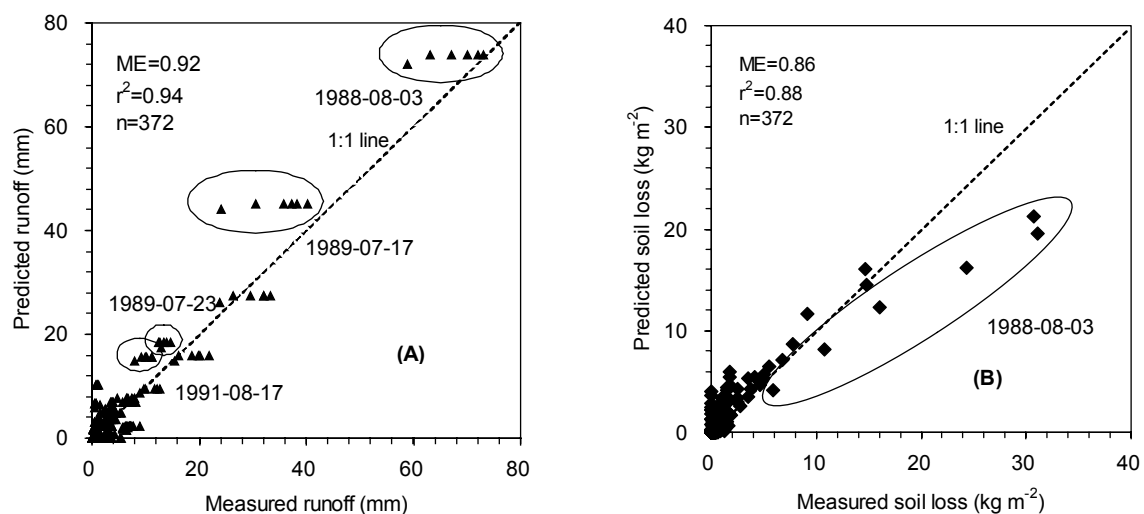

Figure 2 Measured and simulated event runoff (A) and event soil loss (B) on the six slope gradient treatment plots
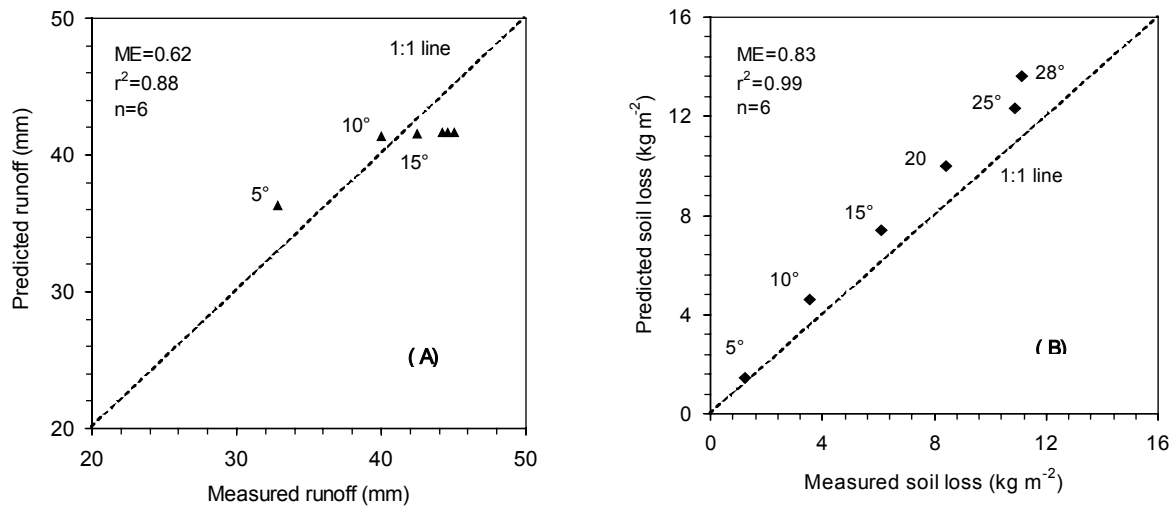
Figure 3 Measured and simulated average annual runoff (A) and average annual soil loss (B) on the six slope gradient treatment plots

6. Acknowledgement

7. References

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